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SUBJECT: Estimate of Hazard Produced by Accidental Release of Gaseous Fission Products from an ORR Fused Salt Capsule Experiment

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FROM: R. E. Adams and W. E. Browning

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Abstract

An accidental release of gaseous fission products from an ORR fused salt capsule, containing 26 mg. of U^{235} , was postulated and the resulting hazard estimated by calculating the maximum external and internal dose an individual could receive from exposure to the gaseous fission products and their decay products. Assuming all the contained gaseous fission products are released, the resulting external and internal dose, to organs other than the thyroid, are insignificant. The dose to the thyroid by radioiodine is considered to be significant. By retaining at least 90% of the iodine isotopes in the experiment system through use of an iodine trap, a large reduction in both the external whole body and internal thyroid doses may be achieved. Therefore, assuming an iodine trap is utilized, it appears that the consequences of an accidental gaseous fission product release from an ORR fused salt capsule experiment would not be serious.

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I. Experiment

The purpose of the experiment is to study the influence of radiation on the corrosion of nickel-base alloys by fused salt fuels in a static system. The capsule, containing 26 milligrams of U^{235} , will be irradiated in core position F-9 of the ORR for a period of approximately 90 days at an estimated thermal neutron flux of 1×10^{14} n/cm²/sec. Fission heat will be removed by passing air through an annulus surrounding the capsule. This cooling air will be discharged into the reactor experiment off-gas system and subsequently released into the atmosphere through the 3039 gas disposal stack.

Design of the capsule provides containment of all fission products, however, a rupture of the capsule wall would allow fission products such as krypton, xenon, and iodine vapor to enter the cooling air stream and be discharged into the atmosphere. Any particulate matter will be removed by an ultimate filter contained in the experiment air discharge line.

II. Radiation Hazard Produced by Release of Fission Gases

A sudden rupture of a capsule during irradiation would release a burst of gas containing radioisotopes of krypton, xenon, and iodine with half-lives ranging from seconds to days, and, in the case of Kr^{85} , years. Safe disposal of these isotopes can be effected by discharge into the atmosphere through the 3039 stack provided the meteorological conditions are favorable and the amount of radioactivity is not too large. This safe disposal is based upon the premise that the fission gas burst is diluted by a sufficient volume of air so that the resulting air concentration is very low. If the release should occur during adverse meteorological conditions when the disposal efficiency of the stack is low, then it is possible for the gas cloud to settle to ground level down-

wind from the stack without sufficient dilution. Under this condition laboratory personnel would be exposed to a slow moving gas cloud which presents both an internal and external radiation hazard.

To evaluate or estimate the resulting external radiation hazard to a person at ground level, all the radioisotopes released and, in addition, all the daughter products produced through decay must be considered. This would include the isotopes of krypton, xenon, iodine, and the decay products, rubidium, strontium, yttrium, cesium, and barium. The internal radiation dose would occur from the isotopes of iodine, rubidium, strontium, cesium, and barium, which will be retained, in part, by organs of the body.

III. Postulated Release and Method for Estimation of Hazard

In order to determine the amounts of the isotopes involved, it is assumed that the capsule has been irradiated for at least 30 days in a thermal neutron flux of 1×10^{14} n/cm²/sec when the rupture occurs. All contained isotopes of krypton, xenon, and iodine are considered to enter the off-gas system. The amounts of the isotopes present under these conditions may be calculated from data published by Blomeke and Todd (3). It is further assumed that the gases require 10 minutes to return to ground level. This time interval of 10 minutes was derived from an estimate of 3 minutes residence time for the gases in the reactor off-gas system and gas disposal stack and 7 minutes for the gas cloud to return to ground level (9). The growth of decay products and decay of the parent isotopes are considered for this time interval and the resulting values were calculated. Table I contains the results of these calculations.

To determine the ground concentration of the various isotopes the efficiency of the gas disposal stack must be estimated. Under adverse conditions, as will be assumed for the release, a stack factor of 1.8×10^{-5} sec/M³ may be derived from data published by Binford and Burnett (2). By

multiplying the number of curies of an isotope released, by the stack factor an estimation of the integrated ground concentration in the units, $\frac{\text{curies} \cdot \text{sec}}{\text{M}^3}$, is obtained.

An estimation of the radiation hazard resulting from the release of a mixture of radiokrypton and radioxenon into the atmosphere of the controlled laboratory area is complicated by the fact that no permissible atmospheric concentration or permissible release rate has been established. It has been proposed that the maximum continuous release of radioisotopes over the entire laboratory area be limited to such a value that the resulting radiation dose from the atmosphere to laboratory personnel be not greater than 10% of the maximum permissible dose for a 40 hour work week (5). On this basis it is possible to obtain a calculated integrated ground concentration ($\text{curies} \cdot \text{sec} / \text{M}^3$) for each isotope in air from which a person would receive 10% of the weekly permissible internal dose, if exposed. The equations and biological data from which these concentrations were calculated may be found in the National Bureau of Standards Handbook 52 and the addendum to NBS Handbook 59 published April 15, 1958.

The total external body dose is calculated by the following relationship which was derived from an equation given in a report by Burnett (4):

$$Z = 2.6 \times 10^2 QE$$

where

Z = external dose (mr)

Q = integrated ground concentration of radioisotope ($\frac{\text{curies} \cdot \text{sec}}{\text{M}^3}$)

E = combined effective beta and gamma decay energy (MeV)

The radiation doses (10% of weekly permissible dose) upon which this hazard evaluation is based are taken to be: (1) 10 mr for external dose to whole body, (2) 30 mr for total internal organ dose, excluding thyroid, and (3) 60 mr for the thyroid (8). These values are not independent because it must be assumed that internal organs of the body are also irradiated by external radiation as well as by radioisotopes deposited from inhalation or ingestion. This fact is taken into account in the evaluation.

IV. Estimation of Radiation Doses Assuming Complete Release of All Contained Gaseous Fission Products

A. External Dose (Table II)

All the radioisotopes contained in the cloud 10 minutes after release are considered to contribute to the external dose. Using the relationship given above, the total external dose to an individual from the release of fission gases would be 0.41 mr or 4.1% of the weekly dose of 10 mr.

B. Internal Dose

1. Internal Dose to Organs Other than Thyroid (Table III)

The decay products of krypton and xenon are considered in this case. The integrated ground concentration of each isotope was calculated in the units, $\frac{\text{curies} \cdot \text{sec}}{\text{M}^3}$, and compared to the calculated integrated ground concentration, in the units, $\frac{\text{curies} \cdot \text{sec}}{\text{M}^3}$, which would produce the weekly dose of 30 mr. A percentage of the weekly dose which each isotope contributes was obtained and the individual contributions were summed. This dose was calculated to be 0.01 mr. The external dose also contributes 0.41 mr. The combined dose is 1.4% of the weekly dose of 30 mr.

2. Internal Dose to Thyroid (Table IV)

The dose to the thyroid was treated separately and on the basis of a weekly dose of 60 mr. In the same manner as above, the internal dose to

the thyroid was calculated to be 31.6 mr. Adding the external dose of 0.41 mr, this equals 52.4% of the weekly dose of 60 mr.

V. Discussion of Calculated Dosages

The external dose and the internal dose to body organs other than the thyroid appear relatively insignificant. The dose to the thyroid from iodine isotopes is more significant. It should be noted that the iodine isotopes also contribute a large fraction of the external dose. It follows that an effort should be made to reduce the quantity of radioiodine released both from the standpoint of thyroid and external whole body dose.

The major portion of radioiodine may be removed from an accidental fission gas release by installation of an iodine trap composed of either activated charcoal or silver-plated copper wire mesh. A reduction in iodine activity by a factor of 10 would be adequate in this application, therefore, considering the ease of handling and fabricating of traps from the wire mesh and its decontamination efficiency of more than 90%, the use of silver-plated copper mesh is proposed. The decontamination efficiency of iodine containing air stream by silver-plated copper mesh has been shown to be greater than 90% at room temperature for traps with depths of 4 to 6 inches (1, 7).

A re-evaluation of the external and internal doses that might be expected will now be made on the basis that 90% of the iodine released from the capsule is retained by the iodine trap.

VI. Estimation of Radiation Doses Assuming an Iodine Trap is Utilized

A. External Dose (Table II)

The removal of 90% of the iodine reduces the external dose to 0.17 mr, or 1.7% of the weekly 10 mr dose as compared to 0.41 mr (4.1%) when an iodine trap is not used.

B. Internal Dose

1. Internal Dose to Organs Other than Thyroid (Table III)

The portion of the internal dose to body organs by rubidium, strontium, barium, and cesium is not changed by the use of an iodine trap since the parents of these isotopes (krypton and xenon) will not be affected. That portion of the internal dose contributed by external radiation will be reduced by removal of 90% of the iodine from the fission gas release. The internal dose on this basis is reduced to 0.18 mr (0.6% of 30 mr dose) as compared to 0.42 mr (1.4% of 30 mr dose).

2. Internal Dose to Thyroid (Table IV)

By use of an iodine trap the total dose to the thyroid by radioiodine and external radiation would be reduced to 3.29 mr (5.46% of 60 mr dose) as compared to 31.6 mr (52.4% of 60 mr dose) when all of the iodine isotopes are allowed to enter the atmosphere.

VII. Comments and Conclusion

It has been shown by calculation that the external dosages produced by the postulated release are very small and that the iodine hazard can be significantly reduced by including an iodine trap in the experiment assembly. The calculated thyroid dose represents a maximum figure since it assumes all the contained iodine is released from the capsule and 10% of this amount reaches the atmosphere. In practice only a fraction of the iodine would be released from the capsule and much of this would deposit on the metal surfaces of the capsule assembly and the particulate filter (6). More than 90% of this fraction would be removed by the iodine filter. Therefore, only a small percentage of the iodine contained in the capsule would find its way into the atmosphere.

A factor to be considered, in addition to radiation exposure to personnel, is possible interference by this activity with sensitive radiation detection instruments in use at the Laboratory. The fission gases, krypton and xenon, would be present in such small concentrations that radiation monitors and laboratory instruments should not be affected. Iodine vapor, however, could deposit or "fall-out" onto building roofs and produce instrument interference until removed by radioactive decay. If an iodine trap is utilized in the experiment system, then the small amount of iodine released by the postulated accident is not considered to be sufficient to cause instrument interference.

An additional factor worth considering, in defense of the safety of the experiment, is that many capsule experiments of this nature have operated successfully in the Materials Test Reactor with a high degree of reliability.

Assuming an iodine trap is incorporated in the system and considering, as a whole, the amount of radioactivity involved, the identity of the isotopes, the pessimistic conditions of the postulated accident, the calculated external and internal doses, and the indicated reliability of the capsule design as shown by prior operating experience, it appears that the probability of such a fission gas release is low, and if it should occur, the consequences do not appear to be serious.

Table I

Contents of Gas Cloud at Time of Release and at Ground Level 10 Minutes Later

Isotope	Curies at Release	Curies, 10 Minutes Later	
		No Iodine Trap	Iodine Trap
Mixed Kryptons	19	8.8	8.8
Mixed Xenons	34	13.4	13.4
Mixed Iodines	31	26.9	2.7
Rb-88	-	1.3	1.3
Rb-89	-	0.7	0.7
Rb-90	-	0.1	0.1
Sr-89	-	8.9×10^{-3}	8.9×10^{-3}
Sr-90	-	1.8×10^{-7}	1.8×10^{-7}
Cs-137	-	1.4×10^{-6}	1.4×10^{-6}
Cs-138	-	1.0	1.0
Cs-139	-	0.5	0.5
Ba-137	-	1.1×10^{-6}	1.1×10^{-6}
Ba-139	-	4.4×10^{-2}	4.4×10^{-2}
Total Curies	84	52.8	28.6

Table II

External Dose at Ground Level 10 Minutes After Release of Fission Gases Under
Adverse Meteorological Conditions

Isotopes	No Iodine Trap		Iodine Trap	
	Dose (mr)	Percent of 10 mr dose	Dose (mr)	Percent of 10 mr dose
Krypton	7.2×10^{-2}	0.72	7.2×10^{-2}	0.72
Rubidium	2.0×10^{-2}	0.20	2.0×10^{-2}	0.20
Strontium	2.2×10^{-5}	-	2.2×10^{-5}	-
Xenon	3.7×10^{-2}	0.37	3.7×10^{-2}	0.37
Cesium	1.9×10^{-2}	0.19	1.9×10^{-2}	0.19
Barium	1.3×10^{-4}	-	1.3×10^{-4}	-
Iodine	2.6×10^{-1}	2.6	2.6×10^{-2}	0.26
Total	4.1×10^{-1}	4.1	1.7×10^{-1}	1.7

Table III

Internal Dose to Organs Other Than Thyroid 10 Minutes After Release of Fission
Gases Under Adverse Meteorological Conditions

Isotopes	No Iodine Trap		Iodine Trap	
	Dose (mr)	Percent of 30 mr Dose	Dose (mr)	Percent of 30 mr Dose
Rubidium	3.0×10^{-4}	1.0×10^{-3}	3.0×10^{-4}	1.0×10^{-3}
Strontium	5.4×10^{-3}	1.8×10^{-2}	5.4×10^{-3}	1.8×10^{-2}
Barium and Cesium	5.7×10^{-3}	1.9×10^{-2}	5.7×10^{-3}	1.9×10^{-2}
External Dose (Table II)	4.1×10^{-1}	1.37	1.7×10^{-1}	5.7×10^{-1}
Total	4.2×10^{-2}	1.4	1.8×10^{-1}	0.6

Table IV

Internal Dose to Thyroid Resulting From Release of Fission Gases Under Adverse
Meteorological Conditions

Isotope	Half-Life	No Iodine Trap		Iodine Trap	
		Dose (mr)	Percent of 60 mr dose	Dose (mr)	Percent of 60 mr dose
I-131	8.05d	11.0	18.4	1.10	1.84
I-132	2.4h	1.5	2.4	0.15	0.24
I-133	20.8h	11.6	19.3	1.16	1.93
I-134	52.5m	1.1	1.8	0.11	0.18
I-135	6.68h	5.6	9.3	0.56	0.93
I-136	86s	0.4	0.6	0.04	0.06
External Dose (Table II)		0.4	0.6	0.17	0.28
Total		31.6	52.4	3.29	5.46

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